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EVALUATION OF SOUND ENVIRONMENT FROM THE VIEWPOINT OF BINAURAL TECHNOLOGY

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INTRODUCTION

Evaluation of a sound environment by the "communications receiver" human hearing is influenced by numerous parameters. Those which are diagrammatically summarized in Fig.1. This shows that a sound event cannot be evaluated according to a single quantity (until now, the A-weighted sound pressure level). This measurement is only one out of numerous parameters which result from the evaluation of a sound event. These parameters can be divided basically into two groups, the predominantly subjective (psychological) and the predominantly objective (physical and psychoacoustical) ones. It is practically impossible to derive an objective parameter from subjective ones. This underlines precisely the necessity for an objectively-based aurally-adequate sound measurement technology. Human hearing is a highly sensitive measuring system, but has only a limited long-time memory. This means that when human hearing has experienced a sound event as unpleasant and annoying, these parameters will continue to pertain, even when the noise is reduced by 2 or 3 dB or even more. When human hearing has been sensitized with respect to a given sound event pattern, it is no longer able to make an objective evaluation when the sound quality or noise component as a whole is modified. Aurally-adequate sound measurement technology is therefore concerned with objectively definable parameters. In this connection, not only the A-weighted sound pressure level is of importance, but also the duration of exposure, the spectral composition, the time structure and also the number and spatial distribution of the sound sources. If a sound event does not originate not from a single but from several sound sources, which may also be spatially distributed, a correct evaluation of the sound event can only be obtained through binaural signal processing.

Binaural technology comprises recording of sound by means of an artificial head measuring system and incorporating an evaluation algorithm analogous to human hearing. Aurally-adequate sound measuring technology is not therefore an alternative to but an important extension of existing sound measurement techniques. In complex sound situations, which cannot be defined in terms of A-weighted sound pressure level alone, it can be used for gathering additional data, necessary for an objective evaluation of the sound event. The following points must therefore be noted:

(a) simple physical measurement values such as A-weighted sound pressure level and third octave spectrum do not provide full information about sound events,

(b) the auditory exent is also determined by the psychoacoustic characteristics of human hearing,

(c) human hearing comprises two input channels which accomplish spatial hearing and therefore, in the case of several spatially distributed sound sources yield results different to those provided by monaural measuring procedures.

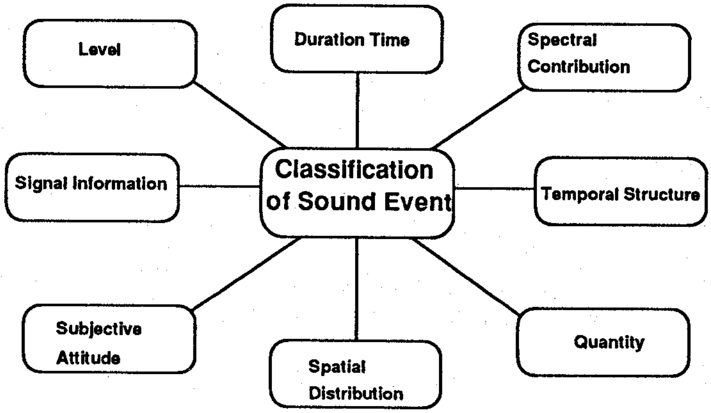


Fig. 1: Representation of parameters of possible relevance for the classification of sound by the human hearing

AURALLY-ADEQUATE SOUND MEASUREMENT TECHNOLOGY

The outer ear is a strongly directional filter. These filtering properties of the human outer ear are brought about by diffractions and reflections, depending on direction, caused by the outer geometry, such as pinna, head, shoulder and torso as well as by resonances which are independent of direction. However, a standard measuring microphone has a linear, frequency-independent level characteristic for all directions of sound incidence. These filter properties of the outer ear are very important for further signal processing in the receiver end "human hearing". An obvious difference between human hearing and conventional acoustic measuring methods is the fact that man has two auditory canals. The second ear is not simply a spare one, but allows for binaural signal processing and pattern recognition in conjunction with directional hearing, selectivity and suppression of noise. In a complex sound situation with various spatially distributed sound sources radiating different signals with the same acoustic power, the elimination of a single sound source leads to a very insignificant reduction of the measured level. In contrast, human hearing is able to perceive considerable changes, depending on the temporal structures of the signals. This binaural signal processing is essential for every-day life: Speech intelligibility in a noisy environment is only possible by this binaural signal processing.

Up to now acoustic measuring technology has consisted only of single-channel sound event analysis, i.e. measurements carried out using a single mono microphone with a spherical directional pattern. Aural evaluation of sound events changes however, when there are not one but several sound sources and when the ear is exposed to sound from several different directions. Fig. 2 illustrates this complex situation. In the left section, the test person is confronted with two signal sources. In the right section, these two signal sources are situated at different sound exposure angles with respect to the ear.

A significant difference immediately becomes apparent on considering a theoretical borderline case in an anechoic environment. If each signal source emitted exactly correlated signals of exactly opposite phase from a position exactly geometrically symmetrical with respect to the center point, they would cancel each other out completely, i.e. no sound pressure level would be measurable. Due to the spatial separation between the ears at the human head and the resulting interaural level and phase differences, human hearing perceives only slight attenuation of low-frequency components, while the high-frequency spectral components impact the human ear almost uncorrelated. For frequencies above 300 Hz, therefore, no further difference is measurable. Whether the signals are emitted in opposite or simultaneous phase, the A-weighted sound pressure level remains unchanged. However, the pyschoacoustic effects such as simultaneous, pre- and postmasking have an influence effect when the masker and the signal to be masked are located at different angles of incidence to the ear. Fig. 3 illustrates this phenomenon using a simple example. Simultaneous masking obtains through 4 kHz noise and a 4 kHz pulse tone in a noise situation in which the third octave noise and the pure tone are located 80° to the right and 50° to the left respectively. Measurement using a standard microphone leads to a result completely different from that obtained when using an artificial head measuring system. Whereas in the first case the pulsating pure tone cannot be perceived, it can clearly be perceived in the second signal when the artificial head microphone signals are played back. However, the difference between the two procedures from a measurement engineering standpoint can also be made clear. The reason for these different effects is partly due to the filtering properties of the human outer ear and partly due to the binaural signal processing of hearing.

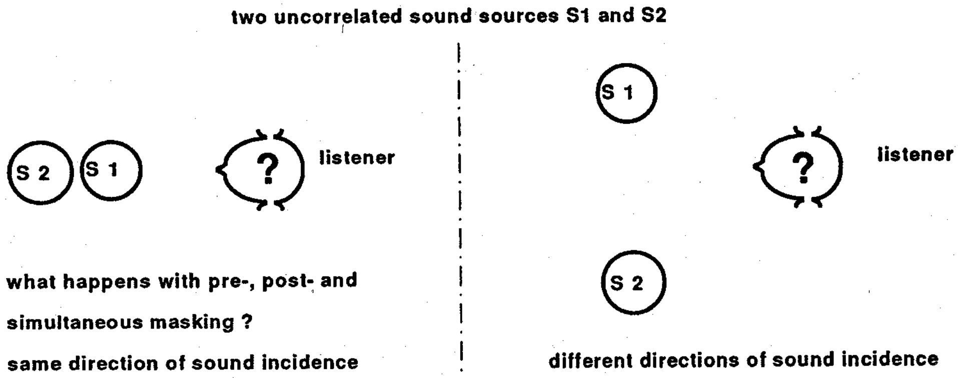


Fig. 2: Illustration of the influence on hearing sensation caused only by the spatial distribution of 2 sound sources

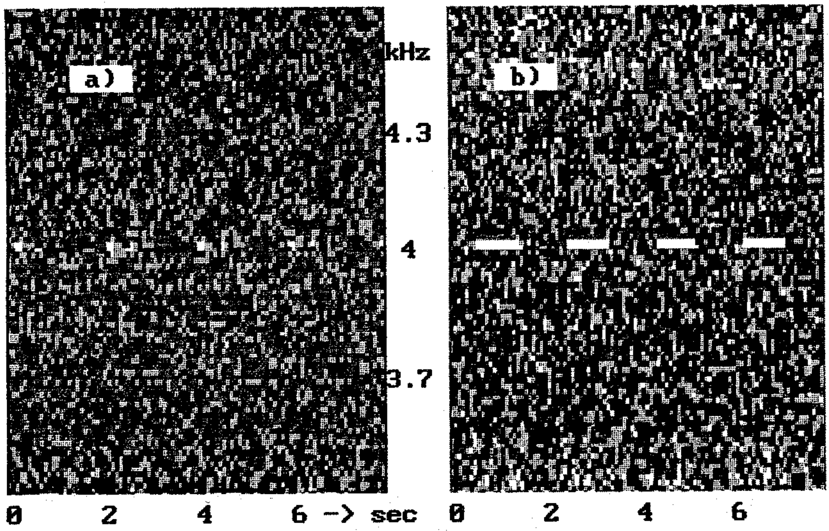


Fig. 3: Changes in simultaneous masking during binaural signal processing under the assumption that the masking and the masked signals (time-pulse 4 kHz sinus tone) are emitted from spatially different directions
(a) recording with a standard microphone
(b) recording with an artificial head measuring system

First examinations have been made for binaural loudness. The masked threshold L_T of pure tones from a direction of sound incidence of 60^0 masked by pink noise L_M = 60 dB has been determined. In one case the noise was a flat wave from the front and in the other one a diffuse sound field. The results as compared to the monaural measurement are represented in Fig. 4. The result shows that the pink noise of the diffuse sound field masks the test tones more strongly than that of the flat sound field. However, at test tone frequencies above 2 kHz the masking effect by the flat sound field is slightly higher (1-2 dB). The binaural masked thresholds measured in this test are about 2-15 dB lower compared to the results achieved by monaural measurements.

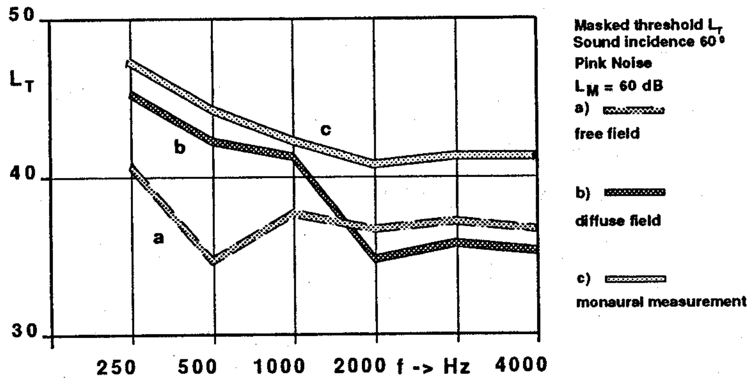


Fig. 4: Masked threshold LT of pure tones in the free field, direction of sound incidence 60°. Masking by pink noise LM = 60 dB

(a) Sound incidence of 0° as a flat wave

(b) Diffuse sound field consisting of six uncorrelated sound sources within the horizontal plane

(c) Monaural measurement

TOWARDS A "PSYCHOTECHNOLOGY" OF NOISE-MANAGEMENT

Since psychoacoustical and psychological factors are of great relevance for complex noise problems, and since such factors cannot be evaluated with physical or biophysical measurements, it is unavoidable to use subjects as measuring instruments. This is no basic restriction, but measurements with subjects (using psychometric methods) tend to cause greater efforts and expenditures than physical or biophysical measurements to the end of arriving at objective, i.e. generalisable results. In order to efficiently apply psychometric methods - which, by the way, are readily available form psychophysics, psychology and sociology - to noise problems, it is necessary to have access to specific tools. In the following, we give a list of such tools which are already available or under current development.

- Devices for authentic reproduction of sound situations for A/B comparison (e.g., with binaural technology);
- techniques to modify sound recording selectively by inserting and taking out components at their apparent location in auditory space;
- improved techniques for the authentic simulation of sounds situations on computers, to the extent of creating virtual auditory environments - eventually coupled with adequate visual and tactile virtual environments.

By the way of state-of-the-art measuring equipment, one may get important hints for basic attributes of the auditory events. However, when it comes to more complex problems, especially such which include cognitive factors, the human ear has to finally perceive the auditory event and the human brain has to make the final judgement. At this point, it is useful to consider the physiological determination of the auditory system: It is the purpose of the auditory system of any organism to gather up and process information from and about the environment, including tasks such as:

- to identify sound sources with respect to their nature and their position and state of movement in space,
- in many species (e.g. man), to provide for interindividual vocal communication.

With regard to auditory information gathering and processing, there are the following reasons to classify a sound as noise, i.e. as being undesired.

- A sound carries information which is unwanted, undesired.
- A sound hinders the perception of desired information and is thus rated as being undesired.

In the first case, if undesired and desired information is delivered simultaneously, the sound components which carry the undesired information are called noise, the other ones are called "signal". In the second case, the sound components which interfere with the desired information transfer are noise, the others signal. The decision of what is signal and what is noise is made by the individual listener in each case and is obviously situation-dependent. In following examples such complex situations are illustrated. In a so-called cocktail-party situation, where several persons talk at the same time, a listener can concentrate on one speaker and consider that person's speech sounds as signal and all other speech sounds as noise.

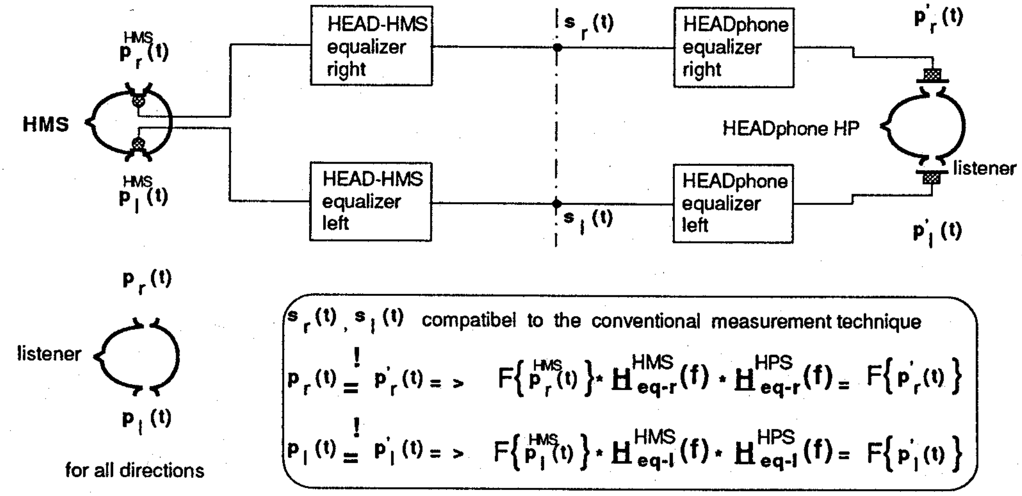
The act of interpretation of the meaning of a sounds draws heavily on the cognition of the listener, i.e., is to a large extent a top-down activity. Auditory-psychology research has identified a number of factors which influence the judgement on the extent of undesiredness of sounds. Cognition does, however, not only modify the interpretation of sound, but already its perception. It is, e.g., well established that perception is to a considerable degree controlled by expectation. We often say that somebody only sees what he/she wants to see. The same phenomenon holds for auditory perception as well. There is evidence that the central nervous system can control more peripheral components of the auditory system by paying attention to specific features of the auditory events. The auditory system can, so to say, focus on certain perceptual auditory features resp. their physical correlates in the sound input to the two ears.

BINAURAL MEASUREMENT TECHNIQUE

It became obvious that a human hearing equivalent analysis of sound quality or noise is only possible if all properties of human hearing are taken into consideration. That means that a simple measuring microphone will not do, but a special artificial head measurement system is needed with transfer functions comparable to human hearing. The analyzer is not just a simple 1/3-octave or Fast-Fourier-Transform analyzer, but an analyzer with high resolution in the time and frequency domains and a high dynamic range comparable to human hearing.

A weighting algorithm which is more complex and complicated than the standard A-weighting curve used up to now is imperative. While the above-mentioned psychoacoustic properties, such as loudness, roughness and sharpness can be determined by adequate algorithms, binaural signal processing of human hearing has yet not been examined completely. Binaural signal processing is not only necessary to recognize the direction of sound incidence or to select individual sound sources from a mixture of sounds. Moreover, the formation of binaural loudness, sharpness and roughness will presumably vary if artificial head signals are analyzed instead of signals recorded with standard microphones.

The principal idea of head-related transmission is shown in (Fig. 5). Two microphone signals recorded with the head, will be equalized to obtain signals which are compatible to conventional measuring microphone output. For subjective evaluation of sound events, these signals were played back using headphones equalized by correction filters to create the same signals in the earcanal of the listener which would be measured if the listener were in the original sound situation as was the artificial head.



$$p_r(t) \overset{!}{=} p'_r(t) => F\{p_r^{HMS}(t)\} \cdot H_{eq-r}^{HMS}(f) \cdot H_{eq-r}^{HPS}(f) = F\{p'_r(t)\}$$

$$p_l(t) \overset{!}{=} p'_l(t) => F\{p_l^{HMS}(t)\} \cdot H_{eq-l}^{HMS}(f) \cdot H_{eq-l}^{HPS}(f) = F\{p'_l(t)\}$$

Fig. 5: Principle of head-related transmission

CONCLUSIONS

The problems of human hearing equivalent sound evaluation described here have been known for a long time. The dB(A) measurement has been used since 1950, because it could be realized relatively simply on the one hand, and on the other hand confusion resulting from different measurement procedures could be avoided. 30 years ago the ISO standardized the dB(A) measurement, but already then pointed to the fact that a human hearing equivalent measurement procedure would have to be standardized. The hitherto known psychoacoustic measurement procedures, in particular the loudness meter, have not been sufficient, as they consider only a part of human hearing equivalent sound analysis. Due to neglect of binaural signal processing, there were frequently doubts in practice whether simple loudness measurement procedures based on recordings with one microphone yield better results than measurements of the A-weighted sound pressure level.

Numerous examinations have shown the significance of the outer-ear transmission properties for stereophonic listening and speech intelligibility in a noisy environment. Hence it follows that the outer-ear transmission properties and binaural signal processing must be very important for sound classification. In all sound situations which cannot be described by one stationary sound source, a binaural sound measurement and noise judgement is necessary to guarantee a satisfactory correlation between measured results and subjective impression. While binaural sound measurement can today be realized without any problems, a lot of basic research for determining binaural sound evaluation is still required. The acoustician has to consider noise problems very thoroughly. The task for the acoustic measurement technique is to create an improved sound quality by a suitable human hearing equivalent sound design.

Consequently, coping with complex noise situations in the way of a comprehensive noise management requires at least two different approaches:
(a) an engineering approach
(b) an artistic approach

Whether this will be realised by collaboration of noise engineers and sound designers or in the way that a new type of expert evolves - the noise manager - future will tell.